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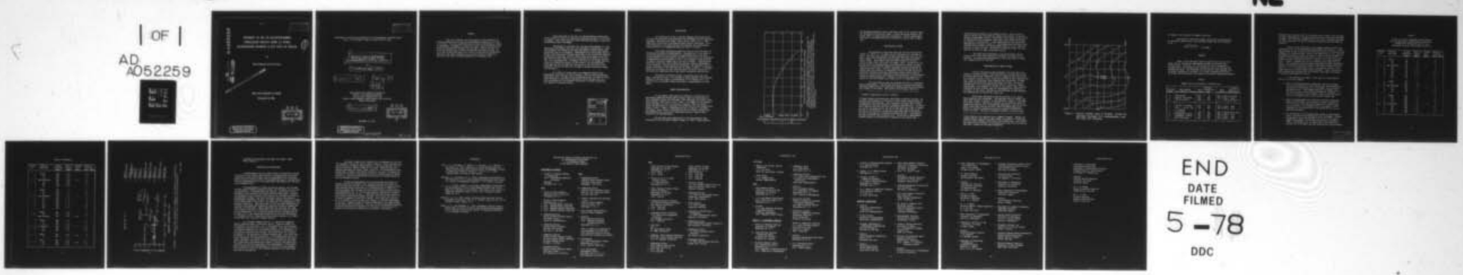

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RELIABILITY AT SEA OF LACOSTE-ROMBERG SURFACE-SHIP GRAVITY METER S-9 WHEN ACCELEROMETER DAMPING IS 0.75 THAT OF CRITICAL

(1)

B.S.

by

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THE A & M COLLEGE OF TEXAS

September 20, 1962

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PREFACE

This is an interim, not final report on the reliability of LaCoste-Romberg meter S-9 when the accelerometer damping is 0.75 that of critical. The tests described were only partly satisfactory; errors in measurement, presumably of electronic origin, were encountered when Browne corrections were greater than 300 mgal. Because the test results were significant at Browne corrections less than 275 mgal, and as it may be some time before the circuit corrections can be made and additional sea tests conducted in the desired range of Browne corrections, this report is being submitted at the present time.

ABSTRACT

Tests were made at sea with the LaCoste-Romberg surface-ship gravity meter S-9 while its horizontal accelerometers were 0.75 critically damped. These tests supersede those reported previously in which the accelerometers were overdamped.

Performance of the meter with the new accelerometers is a very significant improvement over that with overdamped accelerometers. Both the systematic and random errors have been greatly reduced when Browne corrections are low to moderate. Measurements with the present meter at Browne corrections below 275 mgal were found to be reliable and required no empirical correction; those at Browne corrections greater than 275 mgal (300-500) were observed to be in constant error along any one profile in an unchanging sea. Presumably the error at the larger accelerations is of electronic origin, in which case it can be eliminated. Investigations will be made into the source of the difficulty; when corrected, further sea tests will be made at Browne corrections larger than 300 mgal.

As a result of these tests, the anomalies obtained from measurements with meter S-9 since February, 1962 at Browne corrections consistently below 275 mgal can be considered correct in absolute value; those obtained at corrections consistently above 275 mgal can, to a first approximation, be considered indicative of anomaly variations, but incorrect in absolute value.

INTRODUCTION

The reliability at sea of LaCoste-Romberg surface-ship meter S-9 when the horizontal accelerometers were overdamped has been described previously (Dehlinger and Yungul, 1962a, 1962b; Allan, et al., 1962). Significant errors were then observed under certain conditions. To reduce these errors, the manufacturers have modified the accelerometer characteristics; the damping was made 0.75 that of critical.

This report describes reliability tests at sea with meter S-9 containing the modified accelerometers. The objective of the tests is to provide estimates on accuracies of measurements with these meter characteristics in routine gravity surveys; in particular, the accuracies of measurements being obtained in the A. & M. College of Texas program of making a free-air anomaly map of the Gulf of Mexico. Experience has shown that while this type of meter may provide accurate measurements in the laboratory, where motions are sinusoidal, the same meter may not measure accurately at sea when motions are highly irregular. If measurements are to be made in other than calm seas, the meter reliability at sea should be established after each major instrumental modification.

The present reliability tests, as previous ones with this meter, were made on the A. & M. College of Texas research vessel HIDALGO. Results of the tests apply to measurements on the HIDALGO, but it is believed that the present results also apply to measurements on other ships.

METER CHARACTERISTICS

In the present tests meter S-9 consisted of essentially the same gimbal-suspended system used previously when the accelerometers were overdamped (Yungul and Dehlinger, 1962; Dehlinger and Yungul, 1962a, 1962b; Gibson, 1962; Allan, et al., 1962). The damping of the accelerometers was made 0.75 that of critical in January, 1962; the natural period was maintained at 2 minutes (the latter has not been changed since January, 1961). Figure 1 (reproduced as part of Figure 4, Dehlinger and Yungul, 1962a, 1962b) illustrates the error in meter response with accelerometers as a function of acceleration period, based on data supplied by the manufacturers.

Two new Diehl servo amplifiers to the accelerometers were incorporated into the meter system on August 27, 1962. These replaced

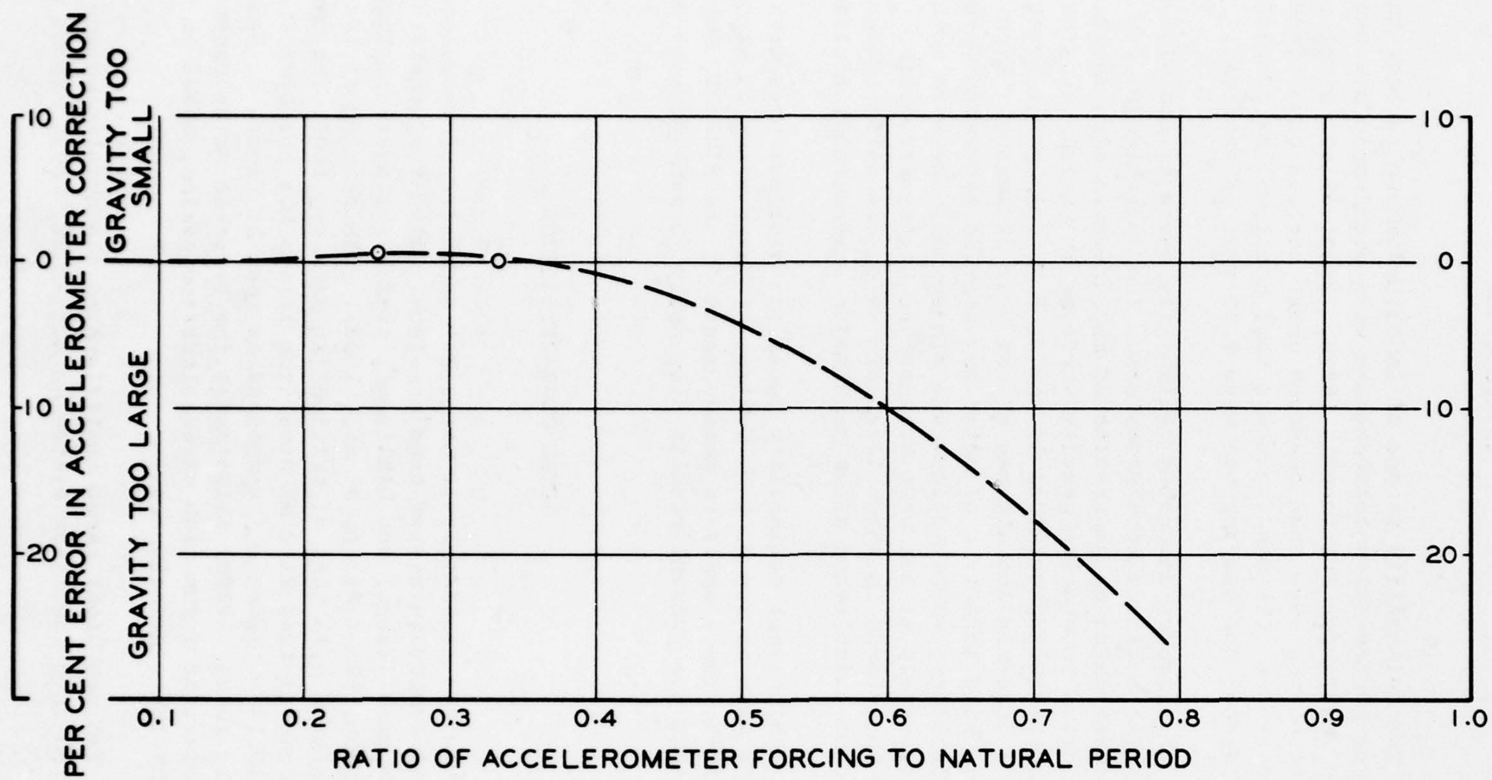

FIGURE 1. ERROR IN HORIZONTAL ACCELEROMETER CORRECTION AS FUNCTION OF ACCELEROMETER FORCING TO NATURAL PERIOD. ACCELEROMETER DAMPING 0.75 THAT OF CRITICAL. CIRCLES BASED ON LABORATORY MEASUREMENTS; DASHED CURVE EXTRAPOLATED, BASED ON THEORETICAL CURVES AS GUIDES.

the Minneapolis-Honeywell servo amplifiers used in all previous tests. The new amplifiers have more power, a faster operating response, and should result in fewer electrical breakdowns*. Gravity measurements obtained on the HIDALGO should be the same with either type of amplifier.

DESCRIPTION OF TESTS

The reliability tests were made past the Pure Oil Platform ($29^{\circ}09'$ N., $94^{\circ}41'$ W.), 12 miles south of Galveston in 9 fathoms of water. The tests were similar to those previous tests past this platform in which the courses were held straight (Dehlinger and Yungul, 1962a, 1962b). The present tests were made during two cruises: 62-H-6 in June, 1962, and 62-H-11 in August, 1962. During 62-H-6 the sea was calm and average Browne corrections did not exceed 100 mgal. During 62-H-11 the sea was rougher and Browne corrections ranged between 50 and 550** mgal. Free-air anomalies obtained during the two cruises were quite similar at comparable values of Browne correction. Electronic difficulty prevented obtaining a harbor base reading at the end of cruise 62-H-6, resulting in some uncertainty in the absolute values of anomalies measured. Because of this and the similarity of results on the two cruises, only cruise 62-H-11 is described here.

Of 11 profiles run past the platform on 62-H-11, 9 provided gravity measurements. The profiles were made in various directions to determine anomaly errors as functions of Browne correction and heading with respect to the waves. Each profile was straight, where the

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* Personal communication with Dr. LaCoste.

** Larger Browne corrections were encountered on several profiles, but the meter occasionally hit the floor at these larger accelerations; no readings were then obtained. Such hitting of the floor had not been encountered in previous cruises at comparable accelerations. The difficulty resulted from the fact that the center shock cord used to connect the top of the gimbal box to the top of the meter cage could not be attached on this cruise; the new servo amplifiers were so fastened to the top of the cage as to prohibit attaching the cord. This problem has been corrected since cruise 62-H-11. Accuracies of measurements obtained should not be affected by omission of this center cord.

course was held constant by an automatic pilot*. Each run was at least 12 miles long, with midpoint nearest the platform, to provide accurate navigational control. Positions of the center and end points of each profile were determined from radar fixes, based on distance and azimuth to the platform. It was estimated that calculated ship headings were accurate to about 1^{o}. Ship speeds were calculated from plotted profile lengths and corresponding times of travel; they were accurate to about 0.2 knot. Errors due to navigation were thus estimated to be within ± 2 mgal along each profile.

The waves were predominantly from the southeast during cruise 62-H-11, with some shifting in direction on several of the profiles. The waves were approximately 4 feet from crest to trough, with lengths from 75 to 100 feet.

DETERMINATION OF ANOMALY ERRORS

Gravity calculations were obtained in the usual way from slopes on the beam records. Along the profiles in which beam motions were quite smooth and continuous, free-air anomalies were calculated at intervals of about 1 mile. Along the profiles in which beam motions were slightly undulating, fewer anomalies were determined, although these were self-consistent along individual profiles. The gravity readings were tied to the base station (Pier 23, Galveston, Texas) reading made in the HIDALGO at the end of the cruise. This value was considered as more reliable than the corresponding base reading at the start of the cruise. Because of the difference in base readings, the anomalies may be as much as 1 mgal high.

Errors were calculated along the profiles at all points where anomalies were determined. The reference free-air anomaly was taken from the map in Figure 2 (a reproduction of Figure 8, Dehlinger and Yungul, 1962b). This map is accurate at the platform, where the anomaly was obtained from a bottom-meter measurement, but may involve small errors away from the platform, where the measurements were based on 8 anchored readings with meter S-9 aboard the HIDALGO in fairly calm seas. The map is considered reliable to about ± 1 mgal;

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* The automatic pilot operated from a magnetic compass. Because the compass normally oscillates a small amount in moderate to rough seas, the pilot hunts somewhat, resulting in ship fishtailing. The fishtailing deviation was estimated to be usually less than 3^{o} and the period less than 1 minute for the seas encountered.

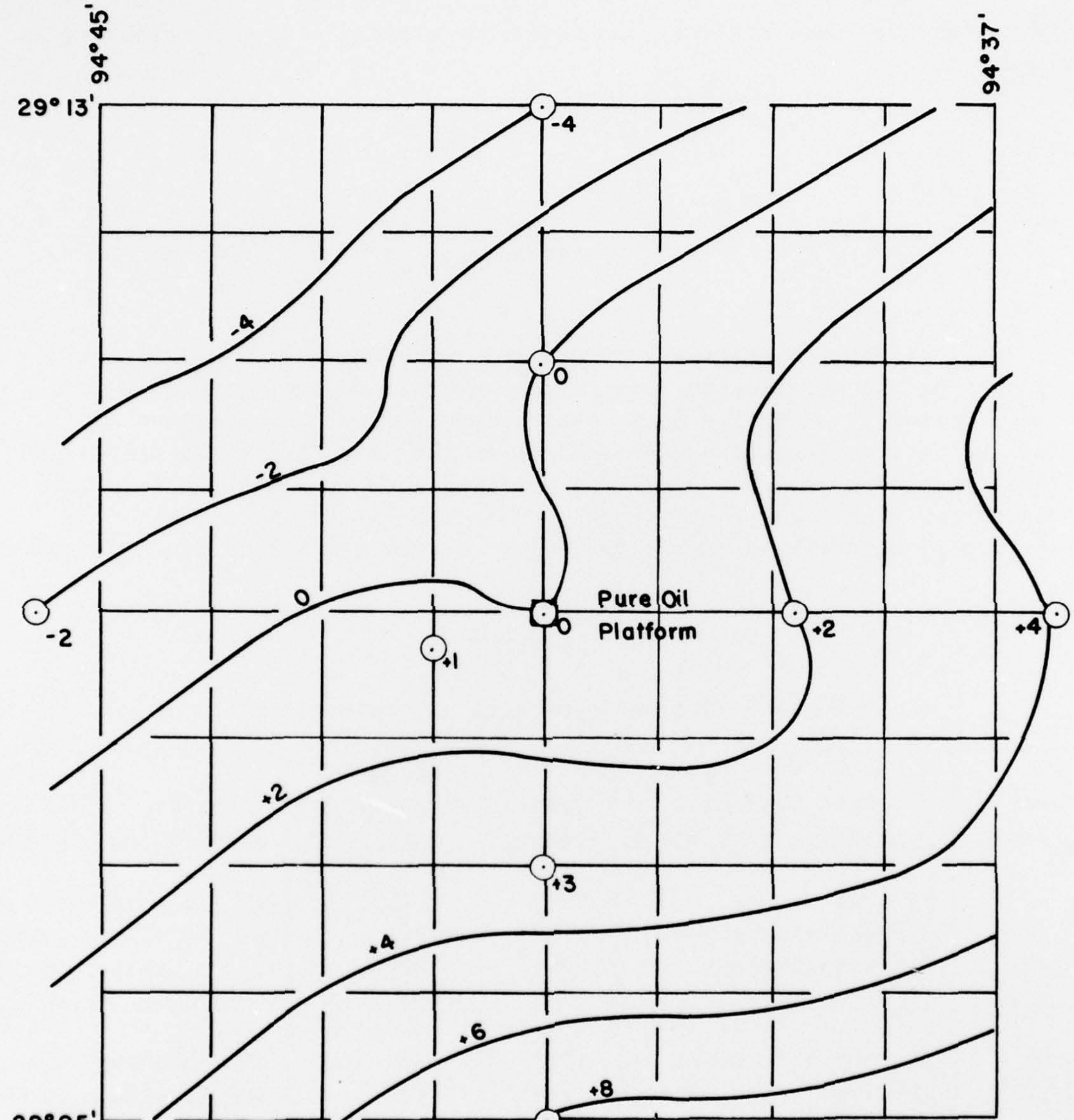

Figure 2. Free-air anomaly map, in milligals. Circles are corrected anchored S-9 measurements near the Pure Oil Platform.

the shape of the contours is somewhat uncertain.

Accuracies of calculated anomaly errors due to uncertainties in navigation, base station, and reference anomaly map were estimated to be

$$\sqrt{2^2 + 1^2 + 1^2} = \pm 2.5 \text{ mgal.}$$

RESULTS

Table 1 lists pertinent factors on profiles 1-8 and 10 (profiles 9 and 11 provided no measurements because of excessive ship accelerations). Profiles 3, 8, and 10 were run with a component of the sea astern; the average Browne corrections were below 300 mgal and readings were good. The remaining profiles were run with headings into the waves, broadside to the waves, or at some intermediate direction; the Browne corrections were then larger and the slope readings less smooth.

TABLE 1

Summary data on 9 profiles of cruise 62-H-11

Profile Number	Ship Heading with Respect to Waves	Ship Heading	Average Browne Corr. (mgal)	Meter Orientation	Average Quality of Measurement
3	With waves	256°	70	45° to ship	very good
8	Approx. with waves	310°	200	45° to ship	good
10	45° with waves	$269\frac{1}{2}^\circ$	200	$\perp$ ship	very good
1	45°-60° into waves	194°	350	45° to ship	good
2	45° into waves, sea shifting	14°	400	45° to ship	poor
4	Into waves	75°	300	45° to ship	fair & poor
5	Broadside to waves	231°	320	45° to ship	fair
6	Broadside to waves	50°	450	45° to ship	poor
7	60° into waves	193°	475	45° to ship	poor

The meter was oriented at 45° to the ship's axis on most of the profiles to permit measurements at Browne corrections which occasionally exceeded 500 mgal. With the meter perpendicular to the ship, the operating range of the accelerometer in the roll direction would have been exceeded on occasion.

Table 2 lists the errors in all anomaly determinations along each profile and the corresponding average Browne corrections. It also lists average errors for each profile and deviations of the observed from average error along profiles. Plots of the observed error as a function of Browne correction are shown in Figure 3, where different symbols represent errors along separate profiles to point to the fact that deviations were small along each profile, in spite of any large systematic error. Figure 3 includes data for all anomalies calculated from the tests. If the slightly undulating beam recordings had been disregarded and only the smooth slopes used, Figure 3 would have consisted of profiles 1, 3, 8, 10, and possibly 4 and 5; the apparent results of the tests would not have been significantly different. Thus, provided the poorer slopes were averaged over sufficiently long times, they appear to indicate measurements correctly.

It is observed from Figure 3 that when the accelerometers were 0.75 critically damped:

1. Meter S-9 measurements were essentially correct at Browne corrections consistently less than 275 mgal (corresponding to horizontal accelerations up to 33,000 mgal) and involved no systematic error. The standard deviation of anomaly error for the profiles at these Browne corrections (profiles 3, 8, and 10) was observed to be ±3 mgal. Most of this was due to errors in navigation and in the reference anomaly map.

2. Meter S-9 measurements were incorrect at Browne corrections greater than 275 mgal and involved a constant (systematic) error but with little scatter (random error) of data along any one profile. The systematic error is thought to have originated in the electronics of the system and not in the measuring mechanism.

3. The reliability of the present meter system is considerably higher than when the accelerometers were overdamped. Whereas no systematic error was observed with the 0.75 critically damped accelerometers (at Browne corrections of 275 mgal or less), a systematic error of nearly 10% of the Browne correction (up to 500 mgal) had been observed with the previously

TABLE 2

Errors in free-air anomalies along profiles with corresponding average Browne corrections, average error along each profile, and deviations in error from average of profile

Profile No.	Position (Latitude)	Browne correction (mgal)	Error in anomaly (mgal)	Average error (mgal)	Deviation from aver. error (mgal)
	29°11'	85	- 3		- 4
	10'	90	0		- 1
	10'	75	- 1		- 2
3	near platform	80	0	+ 1	- 1
	09'	65	+ 1		0
	09'	60	+ 1		0
	09'	65	+ 2		+ 1
	09'	80	+ 2		+ 1
	08'	60	+ 3		+ 2
	08'	60	+ 3		+ 2
	29°06'	240	- 5		- 1
	07'	190	- 5		- 1
8	near platform	200	- 5	- 4	- 1
	10'	230	- 7		- 3
	11'	50	- 1		+ 3
	12'	50	+ 1		+ 5
	29°09'	200	- 2		- 3
	09'	280	- 1		- 2
	09'	250	- 4		- 5
	09'	250	- 3		- 4
10	at platform	200	0	+ 1	- 1
	09'	200	+ 3		+ 2
	09'	190	+ 4		+ 3
	09'	200	+ 4		+ 3
	09'	130	+ 4		+ 3

TABLE 2 (continued)

Profile No.	Position (Latitude)	Browne correction (mgal)	Error in anomaly (mgal)	Average error (mgal)	Deviation from aver. error (mgal)
	29°15'	300	+ 20		+ 3
	14'	300	+ 17		0
	13'	310	+ 17		0
1	near platform	400	+ 19	+ 17	+ 2
	08'	360	+ 18		+ 1
	06'	370	+ 16		- 1
	05'	420	+ 14		- 3
	29°05'	470	- 1		+ 3
	07'	480	- 2		+ 2
	08'	400	- 7		- 3
2	near platform	350	- 6	- 4	- 2
	10'	330	- 6		- 2
	11'	340	- 7		- 3
	12'	400	- 7		- 3
	13'	220	- 6		- 2
	14'	310	+ 1		+ 5
	15'	280	+ 2		+ 6
	29°08'	260	+ 27		- 1
4	09'	350	+ 32		+ 4
	near platform	300	+ 25	+ 28	- 3
	29°12'	285	+ 6		- 1
	11'	340	+ 4		- 3
	10'	340	+ 6		- 1
5	at platform	360	+ 10	+ 7	+ 3
	09'	360	+ 10		+ 3
	06'	350	+ 9		+ 2
6	29°08'	450	+ 23	+ 23	0
	10'	450	+ 23		0
	29°13'	450	+ 30		+ 1
7	11'	500	+ 30	+ 29	+ 1
	05'	550	+ 26		- 3

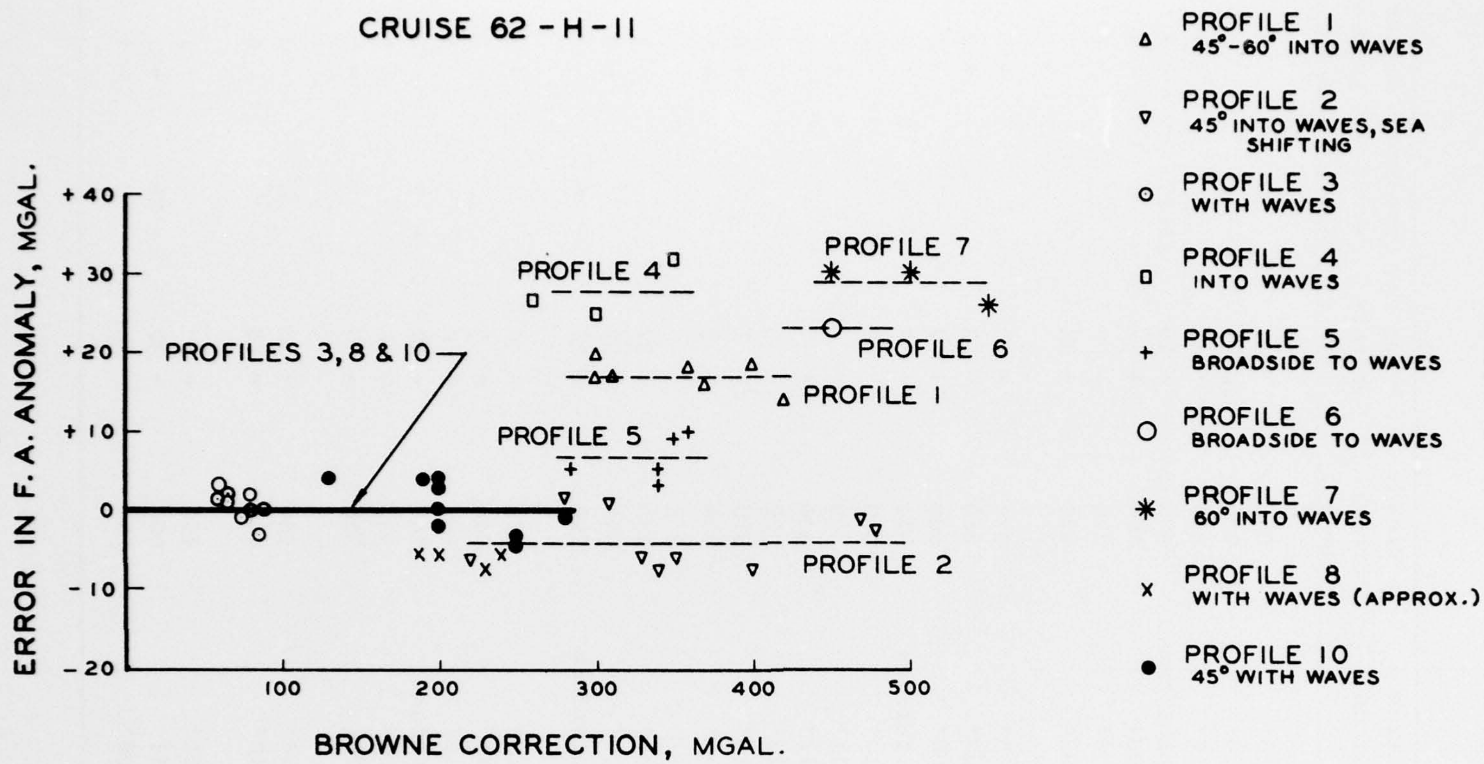

FIGURE 3. ERROR IN FREE-AIR GRAVITY ANOMALY FOR METER S-9 OPERATING WITH 0.75 CRITICALLY DAMPED ACCELEROMETERS.

AUG. 1962

overdamped accelerometers (Dehlinger and Yungul, 1962a, 1962b, Figure 2).

DISCUSSION AND CONCLUSIONS

As measurements with the present meter S-9 involved no systematic error and only small random errors at average Browne corrections consistently less than 275 mgal, gravity measurements with this meter should be quite reliable within the corresponding range of accelerations. The new accelerometers are a very significant improvement over the previous overdamped units.

The measurements at Browne corrections greater than 275 mgal involved nearly constant systematic errors, but the amount of error was not predictable; it depended upon ship heading. Deviations from the systematic error along any one profile were noticeably small. Because the systematic error involved a step function at a Browne correction of approximately 300 mgal, this error can hardly result from incorrect accelerometer responses; the error is almost certainly caused by a defect in the electronics of the system. The cause will be investigated at the earliest opportunity. When the source of error has been determined and corrected, additional sea reliability tests will be made at Browne corrections of 300-500 mgal. Making additional sea tests may take some time, however, because (1) meter repair may involve laboratory testing by the manufacturer, (2) of required advance notice in scheduling the cruises, and (3) the desired sea conditions are often not encountered on a scheduled cruise. Significant tests usually involve 2 to 3 short cruises made over a period of several months.

In a personal communication Dr. L. LaCoste has suggested several possible causes of electronic errors. The most likely is a non-linearity in tooth-count, i.e., a non-linearity in the conversion of measured accelerations to electrical signals. Such might be due to the feed-back amplifiers in the computers being out of adjustment, as involving an incorrect bias voltage. This could result in a partial saturation of the amplifiers at larger accelerations. This factor will be checked at the earliest opportunity. If the amplifiers are out of proper adjustment, the amount would hardly be the same for both amplifiers; one might then saturate at lower accelerations than the other. Such differential adjustments would result in errors that depend upon the amount of correction applied by each accelerometer. The relative amount recorded by each accelerometer is a function of ship heading. The variation of error with ship heading observed in the tests might have such an explanation.

The small random errors observed are a consequence of the fact that systematic errors are zero or nearly constant. While operating with the previously overdamped accelerometers, it had been observed that random errors along a profile ranged up to 10 mgal, depending upon ship heading (Dehlinger and Yungul, 1962b, Figure 7); as the systematic error varied nearly linearly with Browne correction, the error in reading was affected by the actual fluctuations as well as average values of Browne correction. The new accelerometers thus provide for reduced random as well as systematic errors.

Of gravity measurements that have been made with meter S-9 between February and October, 1962, anomalies obtained at Browne corrections less than 275 mgal can be considered correct in absolute value; those obtained along one profile in an unchanging sea at Browne corrections greater than 275 mgal (300-500) involve nearly constant errors. Such measurements are, to a first approximation, indicative of anomaly variations and can be so used. It has been observed along a profile in which Browne corrections averaged 300 mgal, run in June, 1962 north of the Bank of Campeche in the Gulf of Mexico, that there was a positive error in anomaly of about 20 mgal with respect to previous measurements in the area. Possibly anomaly variations observed at the larger Browne corrections involve some errors. This has not been determined completely. If partial saturation of amplifiers is the cause, the reliability of observed variations would depend upon the extent of saturation.

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